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Patentanmeldung Nr. Patent application No. Demande de brevet n°

99109791.6

PRIORITY DOCUMENT

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Der Präsident des Europäischen Patentamts:
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

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Method of transmitting and/or receiving synchronisation sequences

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Description of invention

Method of transmitting and/or receiving synchronisation sequences

Two PSC schemes have been presented in patent applications, namely the hierarchical correlation in DE 19840974.5 and the Golay sequence in DE 19918874.2.

Both schemes allow an efficient computation of the correlation in the mobile station and have been shown to have good correlation properties. For the working assumption simulations under high frequency errors have already been presented

In order to avoid lengthy arguments about marginal relative merits of these two PSC schemes we propose to combine their advantages in a harmonised proposal. That means we propose to use a hierarchical sequence, built from two length 16 constituent sequences, which are themselves hierarchical sequences and their constituent sequences are Golay sequences.
We show that this proposal has a lower complexity than each of the above mentioned PSC schemes while maintaining the synchronisation properties even under high frequency errors. We therefore suggest to use this harmonised approach for the PSC.
Such a selection of the PSC would also simplify the pending decision about the SSC scheme by narrowing down the number of necessary simulations to be considered, because the performance of a SSC scheme can only be judged in combination with a particular PSC scheme.
The paper is organised as follows:

- First we present the proposed PSC
- Second we show how it can be utilised for efficient correlation and show that the complexity is lower than for any of the previous proposal

- Third we present simulations results under no and high frequency error
- Finally we propose this new PSC code to be used and provide a text proposal for S1.13

In this contribution we show that there is almost no difference in slot synchronisation performance for the proposed code in comparison to the working assumption.

Generalised Hierarchical Golay Sequence

For the 1st step of cell search procedure the working assumption for UMTS is to use a hierarchical correlation sequence for the PSC code. The code is generated by two constituent sequences, using the formula

$$y(i) = X_2(i \bmod 16) \cdot X_1(i \operatorname{div} 16) \quad \text{for } i = 0 \ldots 255 \qquad (2$$

Note that in this representation the elements of the binary sequences are {-1,+1}. Then the multiplication has to be changed against exclusive or operation to achieve equivalent results.

We now propose to combine the advantages of the generalised hierarchical and the recursive Golay set-up in a harmonised way. That means we build the constituent length 16 sequence X_1 as a (generalised) hierarchical sequences whose constituent sequences are again selected to be two (length4) Golay sequences. X_2 is selected to be a Golay sequence.

Obviously, selecting hierarchical sequences or Golay sequences again as the constituent sequences, a further saving in complexity can be achieved. However, we found it is necessary to somewhat generalise the definition of the hierarchical sequences (for the hierarchical sequence forming the constituent sequence X_1) and to select the best suited parameters for the Golay sequences. This optimisation was done using a computer search.

The construction principle of the hierarchical sequences can be generalised. Up to now one of the constituent sequences was repeated in its full length, the repetitions were modulated with the value of the corresponding element of the other constituent sequence. We now generalise this and allow only the first half (or an other fraction, but we will actually use the half) to be repeated, followed by the second half and the repetitions there of. The repetitions are modulated with the other constituent sequence as was the case for the non generalised hierarchical sequence. We introduce the parameter s which indicates the part of the constituent sequence which, is repeated as a single chunk.. The formula describing the generalised approach would be:

$$X_1(i) = X_4(i \bmod s + s\cdot(i \operatorname{div} sn_3))\cdot X_3((i \operatorname{div} s) \bmod n_3) \quad \text{for } i = 0..n_3\cdot n_4 \tag{2}$$

Setting $s=n_4$ would give us again the standard hierarchical sequence.

We now propose to combine the advantages of the generalised hierarchical and the recursive Golay set-up in a harmonised way. That means we build the constituent length 16 sequences of the 256 chip hierarchical sequence from a Golay sequence and a (generalised) hierarchical sequences whose constituent sequences are again selected to be two (length4) Golay sequences.

X_1 is defined to be the length 16 Golay sequence obtained by the delay matrix D_2 = [8, 4, 1,2] and weight matrix W_2 = [1, -1, 1,1]

X_2 is a generalised hierarchical sequence using the formula above, selectiong s=2 and using the two Golay sequences X_3 and X_4 as constituent sequences.X_3 and X_4 are defined to be identical and the length 4 Golay sequence obtained by the delay matrix D_3 = D_4 = [1, 2] and weight matrix W_3 = W_4 = [1, 1].

Using the following recursive relation as described in

Siemens „A new Hierarchical Correlation Sequence with good Properties in Presence of a Frequency Error" 3GPP TSG RAN W1 Tdoc 99/146:

$$a_0(k) = \delta(k) \text{ and } b_0(k) = \delta(k) \qquad (4$$

$$a_n(k) = a_{n-1}(k) + W_n \cdot b_{n-1}(k-D_n),$$

$$b_n(k) = a_{n-1}(k) - W_n \cdot b_{n-1}(k-D_n),$$

$$k = 0, 1, 2, \ldots, 2^N,$$

$$n = 1, 2, \ldots, N.$$

While this makes the definition of the sequence somewhat complicated, the correlation becomes much less complex because efficient Hierarchical correlators and Golay correlators can be combined. One possible implementation of the entire correlator could be as shown below. It is called a pruned Golay correlator, because at some stages one of the outputs is pruned and instead the other output is used as input for the next stage.

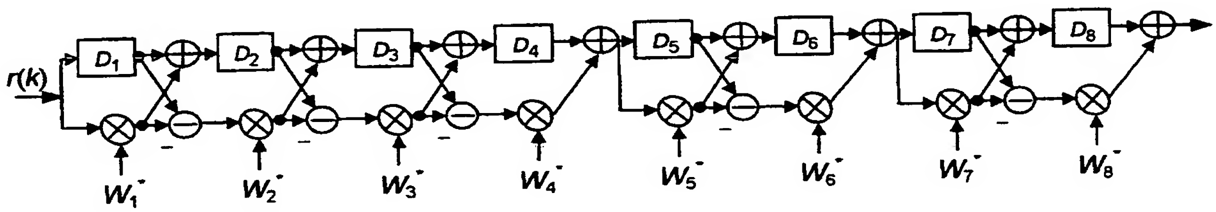

Figure 1: Efficient Pruned Golay Correlator for generalised Hierarchical Golay sequence.

The vector D is given by D = [128, 16, 64, 32, 8, 4, 1, 2] and W = [1, -1, 1, 1, 1, 1, 1, 1]. This correlator only requires 11 adds per correlation output.

We name the code obtained from the working assumption S_{new} and the generalised Hierarchical Golay one GHG for the rest of this paper. The latter offers in comparison to a code with plain Hierarchical or Golay based structure additional advantages due to a efficient calculation of correlation sum. Simulations will show, that there is now significant difference in slot synchronisation performance of the presently discussed PSC codes even in presence of a higher frequency error. The benefits of this proposal are as follows:

- all benefits of the hierarchical sequences are maintained
- The change can be regarded as being only a minor change in the constituent sequences, X_1 and X_2
- the 1st step of initial cell search can be executed more efficientby using the proposed code compared to the Hierarchical only or Golay only scheme
- there is no noticeable difference in slot synchronisation performance between the new choice in comparison to the old selection.

Complexity comparison of correlation sequences

The complexity of any correlation scheme depends heavily on the selected architecture and technology, so direct comparisons between schemes having a rather different construction principle are very difficult. Therefore it is probably impossible to tell unambiguously, whether the plain hierarchical or the plain Golay sequences show the lower complexity. Basically the Golay sequences need fewer adders while the hierarchical sequences allow a more regular implementation of the delay storage which favours a RAM implementation for an ASIC design. In the following we will compare the Hierarchical Golay sequences against both plain schemes and show they have at most the same complexity, but most likely have a lower complexity than any of the two plain schemes. While this analysis will not provide us with absolute figures (they are too heavily technology dependant) it has the advantage of being almost as convincing as a mathematical proof (but we wont take the burden to try to formulate it in a mathematical way).

Comparison against plain Hierarchical correlation scheme

The following shows the general correlation scheme for the Hierarchical correlation:

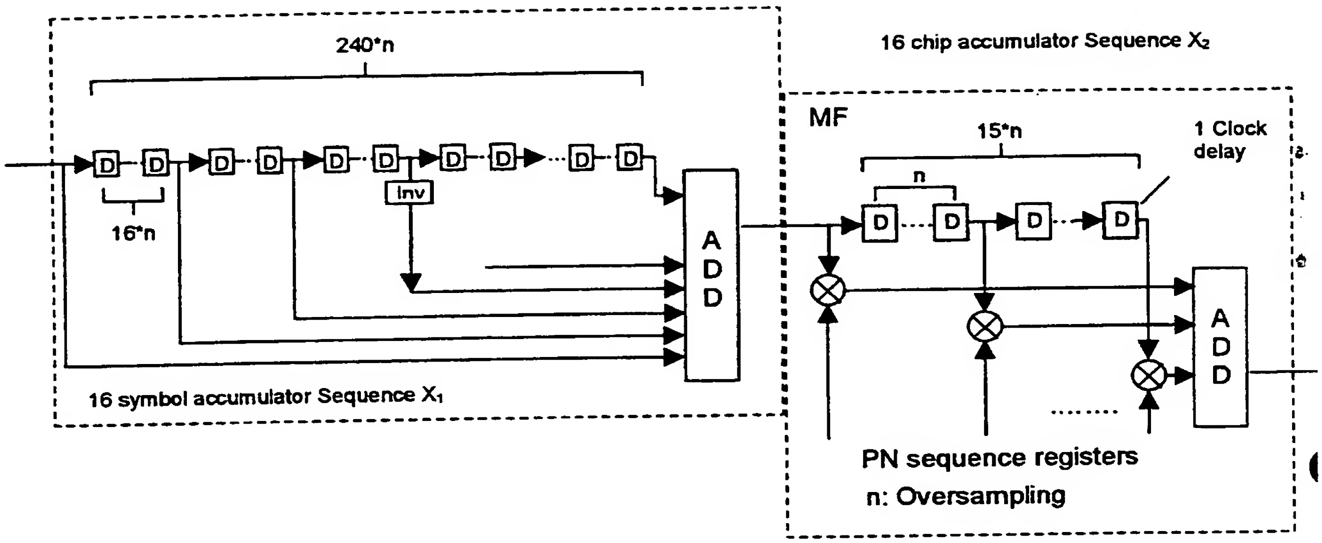

Figure 2: Efficient Correlator for plain hierarchical sequence.

The Hierarchical correlation consists of two concatenated matched filter blocks, each performing a standard correlation over one of the constituent sequences. We assume that the correlation over X_1 (16 symbol accumulation) is done before the correlation over X_2 (16 chip accumulation). Note this is possible as an implementation option without changes to the standard, because both matched filter blocks (enclosed in dotted lines in the above figure) are linear systems which can be connected in either order. In this way, all the 240 *n delay lines can be implemented with the minimum wordlength as no accumulation is done before and therefore no signal to interference gain is achieved.
The Hierarchical Golay sequence is still at the same time a Hierarchical sequence, so any hardware which is already designed can simply be reused for the Hierarchical Golay sequence.This can be done by simply changing the two constituent sequences although a more efficient solution is offered by the (generalised) Hierarchical approach as described above. This proves, that the new sequences have at most the same complexity as the current working assumption.
Reusing existing hardware may not be of prime importance for the commercial terminals to be used when the service is ope-

ned to the public, but it certainly eases the design of pre-commercial prototypes to be used in field trial systems and to check interworking with base station prototypes of various vendors to collect valuable experience for the final designs and to assure a smooth launch of the service afterwards.
As mentioned, if felt advantageous for the selected technology, one or both of the matched filter blocks can be replaced again by a (generalised) hierarchical sequence and by an Efficient Golay Correlator (EGC).

The complexity is then almost certainly smaller than for the plain hierarchical correlation. So almost certainly the complexity of the Hierarchical Golay correlation sequence will be lower than the correlation of the plain Hierarchical sequence..

Comparison against plain Golay correlation scheme

The following shows the general correlation scheme for the Efficient Golay correlator (EGC):

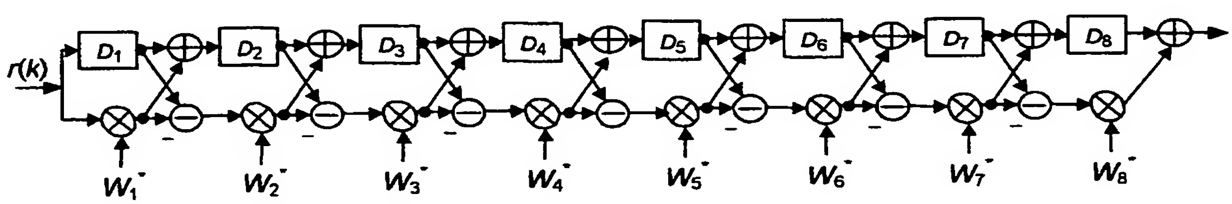

Figure 3: Efficient Golay Correlator for plain Golay sequence.

An efficient Hierarchical Golay correlator has almost the same configuration, except that two adders can be omitted:

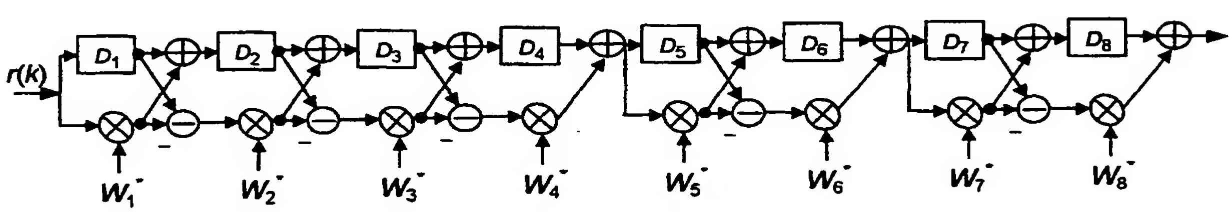

Figure 4: Efficient Golay Correlator for generalised Hierarchical Golay sequence.

Obviously, saving two adders out of 15 will bring down the complexity of the scheme accordingly. Further more, due to the structure of the hierarchical correlation which allows to apply other design optimisations alternatively or together with the EGC, the total saving for an optimised design will most likely be even higher.

Simulation performance

We have investigated the slot synchronisation step on a 3 km/h one ray Rayleigh fading channel for different chip to noise ratios (CNR) under no and high frequency error. We show that there is virtually no difference in slot synchronisation performance for the proposed code GHG in comparison to the working assumption S_{new}. We have results for using 24 slots averaging. Together with the PSC a secondary synchronisation channel is transmitted randomly chosen to be one of 32 symbols as described in

Siemens „A new Hierarchical Correlation Sequence with good Properties in Presence of a Frequency Error" 3GPP TSG RAN W1 Tdoc 99/146

.The plot shows, that there is no significant difference between the current Hierarchical PSC code scheme S_{new} and the new generalised Hierarchical Golay proposal GHG for no frequency error and even a high frequency error of 10 kHz. Compared to the hierarchical code S_{old} proposed initially all discussed PSC codes show better properties (especially in presence of higher frequency error)

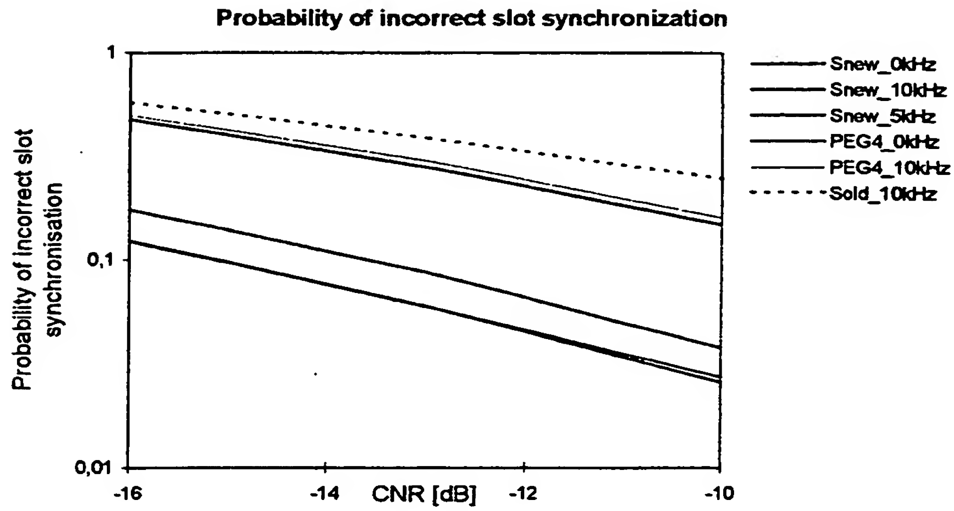

Figure 5: Simulation results <editors note Figure to be updated with the final selection of the code >

The proposed sequence has better autocorrelation properties in particular at 10 kHz than the previous working assumption Sold (broken curve). The plot suggests, that the synchronisation properties of GHG are practically optimal.

Conclusion

We propose to use the generalised hierarchical Golay sequences to be used for the PSC in order to take advantage of the reduced calculation complexity. The complexity will be reduced from 30 adds per output sample for the present working assumption to 11 adds only. This also outperforms the Golay sequences which would need 15 adds.
As shown by simulations the new PSC selection will still obtain the same performance under both low and high frequency errors. The new PSC scheme can be used together with all currently discussed SSC schemes. Due to a lower computational complexity less dedicated hardware is needed and a lower power consumption is achieved.

Note that previously the sequence was first defined binary (0, 1) and then mapped to a bipolar representation (1, -1).

Because the Golay sequences can better be described with the final bipolar representation, only the later is used. Consequently the definition of the hadamard matrix is changed to bipolar representation as well.

5.2.3.1 Code Generation

The Primary and Secondary code words, C_p and $\{C_1,\dots,C_{17}\}$ are constructed as the position wise addition modulo 2 of a Hadamard sequence and a fixed so called generalised hierarchical Golay sequence y. The Primary SCH is furthermore chosen to have good aperiodic auto correlation properties.
The hierarchical sequence y is constructed from two constituent sequences x_1 and x_2 of length n_1 and n_2 respectively using the following formula:
$y(i) = x_2(i \bmod n_2) * x_1(i \operatorname{div} n_2),\ i = 0 \dots (n_1 * n_2) - 1$

The constituent sequences x_1 and x_2 are chosen to be the following length 16 (i.e. $n_1 = n_2 = 16$) sequences:

$x_1(i) = x_4(i \bmod s + s*(i \operatorname{div} sn_3)) * x_3((i \operatorname{div} s) \bmod n_3),\ i = 0 \dots (n_1 * n_2) - 1$
X_1 is a generalised hierarchical sequence using the formula above, selecting s=2 and using the two Golay sequences X_3 and X_4 as constituent sequences.
X_2 is defined to be the length 16 (N_2=2) Golay sequence obtained by the delay matrix $D^2 = [8, 4, 1,2]$ and weight matrix $W^2 = [1, -1, 1,1]$
X_3 and X_4 are defined to be identical and the length 4 (N=2) Golay sequence obtained by the delay matrix $D^3 = D^4 = [1, 2]$ and weight matrix $W^3 = W^4 = [1, 1]$.
The Golay sequences are defined using the following recursive relation:

$$a_0(k) = \delta(k) \text{ and } b_0(k) = \delta(k)$$
$$a_n(k) = a_{n-1}(k) + W_n \cdot b_{n-1}(k-D_n),$$
$$b_n(k) = a_{n-1}(k) - W_n \cdot b_{n-1}(k-D_n),$$
$$k = 0, 1, 2, \dots, 2^N,$$
$$n = 1, 2, \dots, N.$$

a_N then defines the wanted Golay sequence.

The Hadamard sequences are obtained as the rows in a matrix H_8 constructed recursively by:

$$H_0 = (1)$$

$$H_k = \begin{pmatrix} H_{k-1} & H_{k-1} \\ H_{k-1} & -H_{k-1} \end{pmatrix}, \quad k \geq 1$$

The rows are numbered from the top starting with row *0* (the all ones sequence).

The Hadamard sequence *h* depends on the chosen code number *n* and is denoted h_n in the sequel.

This code word is chosen from every 8^{th} row of the matrix H_8. Therefore, there are 32 possible code words out of which 18 are used.

Furthermore, let $h_n(i)$ and $y(i)$ denote the *i*:th symbol of the sequence h_n and *y*, respectively.

Then h_n is equal to the row of H_8 numbered by the bit reverse of the 8 bit binary representation of *n*.

The definition of the *n*:th SCH code word follows (the left most index correspond to the chip transmitted first in each slot):

$C_{SCH,n} = < h_n(0)*y(0),\ h_n(1)*y(1),\ h_n(2)*y(2),\ \ldots, h_n(255)*y(255) >$,

The Primary SCH and Secondary SCH code words are defined in terms of $C_{SCH,n}$ and the definition of C_p and $\{C_1, \ldots, C_{17}\}$ now follows as:

$C_p = C_{SCH,\ 0}$

and

$C_i = C_{SCH,i}$, $i=1,\ldots,17$

The definitions of C_p and $\{C_1, \ldots, C_{17}\}$ are such that a 32 point fast Hadamard transform can be utilised for detection.

Claims:

1. Method of transmitting and/or receiving synchronisation sequences, whereby the sequence is composed of two constituent sequences whereby the first sequence is repeated as often as there are elements of the second sequence, whereby all elements of the first sequence of a specific repetition are modulated with the same element of the second sequence, whereby the repeatitions of the first sequence are interleaved with each other.

2. Method of transmitting and/or receiving synchronisation sequences, whereby the sequence $S(i)$ *of length* $(n_1 * n_2)$ is composed of two constituent sequences x_1 *and* x_2 *of length* n_1 *and* n_2 according to the formula $S(i) = x_2(i \bmod s + s*(i \operatorname{div} sn_2)) * x_1((i \operatorname{div} s) \bmod n_1)$, $i = 0 \ldots (n_1 * n_2) - 1$.

3. Method of transmitting and/or receiving synchronisation sequences, as claimed in any of the preceding claims, whereby the constituent sequences are themselves composed from other constituent sequences as described above or from Golay sequences.

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EPO-Munich
52
18. Mai 1999

Abstract

Method of transmitting and/or receiving synchronisation sequences

A synchronisation sequence is composed of two constituent sequences whereby the first sequence is repeated as often as there are elements of the second sequence, whereby all elements of the first sequence of a specific repetition are modulated with the same element of the second sequence, whereby the repeatitions of the first sequence are interleaved with each other.